ANTENNA STUDY

for the

NATIONAL OCEANIC SATELLITE SYSTEM (NOSS)

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ABSTRACT

Conceptual consideration of the antenna requirements for the National Oceanic Satellite System and means to extend and incorporate the type of feed design utlizied on the Scanning Multichannel Microwave Radiometer (SMMR) lead to three possible design approaches.

It is considered not feasible to add a 94 GHz capability to the SMMR horn and maintain high beam efficiency and low insertion loss. Also, it is not practical for the SMMR type horn to produce the different aperture illuminations desired at some frequencies, hence a single prime focus feed is not recommended.

Three concepts capable of meeting most of the goals are described. One concept utilizes a subreflector, as in an offset cassegrain. The subreflector is a quasi-optical diplexer so that one or two single frequency horns of desired illumination angle radiate through while four or more frequencies from an SMMR type horn are reflected from it. With this design, performance objectives can be realized.

A four horn, prime focus cluster is considered a simple and practical approach of generating non-concentric beams. However, beam efficiency is not expected to reach 90%.

The third concept utilizies a separate feed and one meter reflector for the higher frequencies. An SMMR type multifrequency horn is used as a prime feed for the main reflector. This offers better beam efficiency and options for additional frequencies.

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1.0 BACKGROUND

The preliminary requirements for the radiometer antenna on the NOSS program calls for multifrequency four meter reflector aperture with a dual polarized feed. Six, or more, frequencies are desired and all beams must have high beam efficiency. A similar unit, utilized on the Seasat A and Nimbus G vehicles, employed five dual polarized frequencies with a .8 meter aperture. All frequencies were incorporated in a common feed horn and were designed to illuminate the entire aperture. The feed was fixed while the reflector scanned, hence, the feed was located on the scan axis. The NOSS requirement under consideration can be viewed as an extension of the SMMR design. The essential differences being:

1.) The reflector aperture is four meters, rather than .8 meter.

2.) A sixth frequency must be added (94 GHz), extending the spectrum coverage from about 6:1 to 14:1.

3.) Optional additions of 1.4 GHz and three channels near 55 GHz are desired.

4.) Higher frequencies should use less than the full aperture, so that the beamwidths generated will not be less than the .26 degrees realized at 21 GHz.

5.) 4.3 GHz may be substituted for the 6.6 GHz channel.

2.0 DESIGN APPROACHES

2.1 Single Feed

An obvious approach, and probably most desirable solution, is to extend the design technique used on SMMR to accomodate the addition of 94 GHz into a single feed. This is an extension of the operating band from about 6:1 to 14:1. Consideration of the moding and filtering problems expected over such a band reveal several problems.

SMMR had its lowest frequency (6.6 GHz) fed through the sides of a corrugated conical horn,[1,2] and four frequencies from 10.7 to 37 GHz fed through a common waveguide at the vertex. 37 GHz radiated as an independent dual mode (TE_{11} + TM_{11}) aperture[3]. At 21.0 GHz a small degradation occurred because a higher order hybrid mode was excited at the junction of the horn and its feed waveguide. This shows that the limit over which a circular waveguide can feed a corrugated conical horn, without overmoding, is approximately 2:1. One much higher frequency can be incorporated by using the dual mode concept, but the choice of illumination angles from the horn and dual mode aperture must be compatible and are very limited. Additional lower frequencies may be introduced through the sides of the horn, within the limits over which ring-loaded corrugations can be designed and fabricated to produce the required capacitive impedance over the proper regions of the conical horns internal surface. This requirement imposes theoretical limitations on the

choice of frequencies that can be incorporated.

The possible limitations imposed by the filter requirements for isolation between frequencies is theoretically less-limiting than the above. That is, the low-pass filters required on several input ports simply need to reject all higher frequencies. A low-pass waffle iron filter can be designed to pass 10.7 GHz while rejecting 18, 21, 37 and 94 GHz, but the size, tolerances and insertion loss become impractical.

Within the limits of the above constraints, only one arrangement of a six frequency feed appears feasible. Feed 6.6 and 10.7 GHz through the sides of the horn, at different longitudinal positions. Utilize a circular waveguide at the vertex for unimodal operation at 18, 21 and 37 GHz, and dual mode operation at 94 GHz. Besides the possible moding degradation at 37, and high filter losses, the main difficulty with this design is that substantially different illumination angles at 37 and 94 GHz cannot be obtained. If the feed flare angle is increased, the five lower frequencies can be broadened, leaving 94 GHz at about half the width. Thus, the required difference in widths cannot be reached. Furthermore, a wide flare feed implies a short focal length on the illuminated reflector. This gives rise to high cross-polarization.

It is concluded that a six frequency feed, operating over a 14:1 band with different illumination angles at some frequencies is not a feasible design approach.

Multiple feed horns appear necessary to accomodate frequencies over such a wide range and to produce the different illumination angles desired.

2.2 Multiple Feed Techniques

2.2.1 Prime Focus Cluster

Offset feeds in a single paraboloid to produce displaced beams is simply not practical when using wide flare corrugated conical horns to obtain high beam efficiency. The wide flare corrugated conical horn produces low spillover loss, but has an aperture considerably larger than conventional horns and their phase center is deep inside, near the vertex. Hence, a cluster of such horns with different diameters and flare angles would require a very wide separation to avoid shadowing and the beams produced would be many beamwidths apart. The beam efficiency of a paraboloid's beam when scanned more than a few beamwidths off axis, degrades rapidly. (This is a function of the paraboloids f/D ratio, with long focal lengths having less degradation.)

Narrow flare angle horns can be used in a cluster to produce multiple offset beams. Such horns have a smaller aperture for a given beamwidth than the wide flare corrugated conical horn. However, their pattern is diffraction limited, which means there will be sidelobes and the beamwidth will vary inversely with frequency. Either the corrugated[1] or dual mode[3,4] horn could be used, and either could be conical or pyramidal. It is feasible to design four horns to cover six frequencies and to obtain the illuminations required. 6.6 (or 4.3) GHz requires a separate horn, as does 10.7 GHz, also 18 and 21 GHz are close enough together that a single horn can be utilized. 37 and 94 GHz will illuminate reduced portions of the aperture, hence, the horn apertures required are larger in wavelengths, but physically will be about the same size as used at 18/21 GHz. Hence, 37 and 94 GHz can use a common horn.

For example, Table I lists estimated sizes for a four horn cluster, operating at six frequencies.

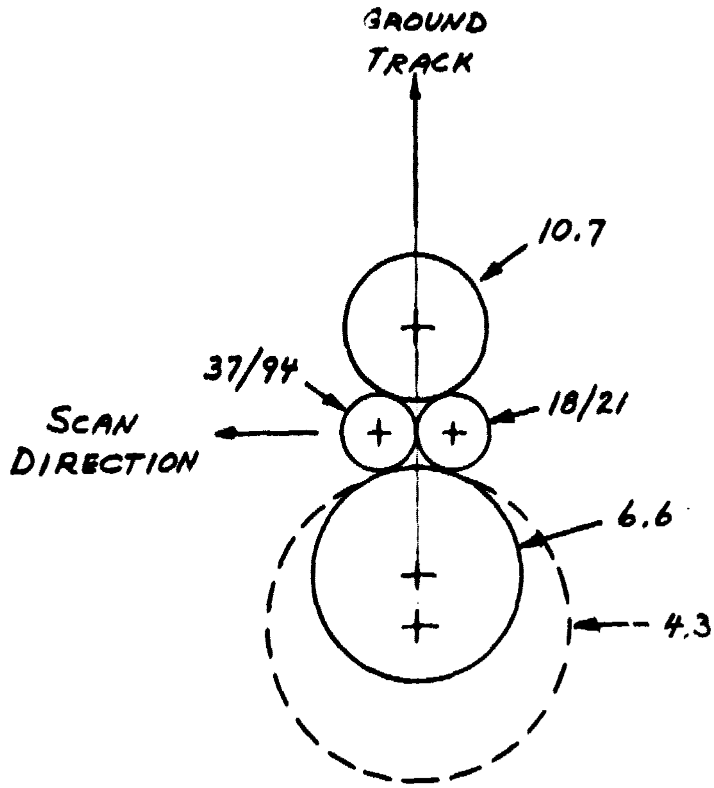
TABLE I

HORN NO.	FREQUENCY	ILLUMINATION ANGLE	HORN O.D.
1	4.3 or 6.6 GHz	70°	3
2	10.7	70	1.6
3	18 and 21	70	1.6
4	37	35	1.6
4	94	14	1.6

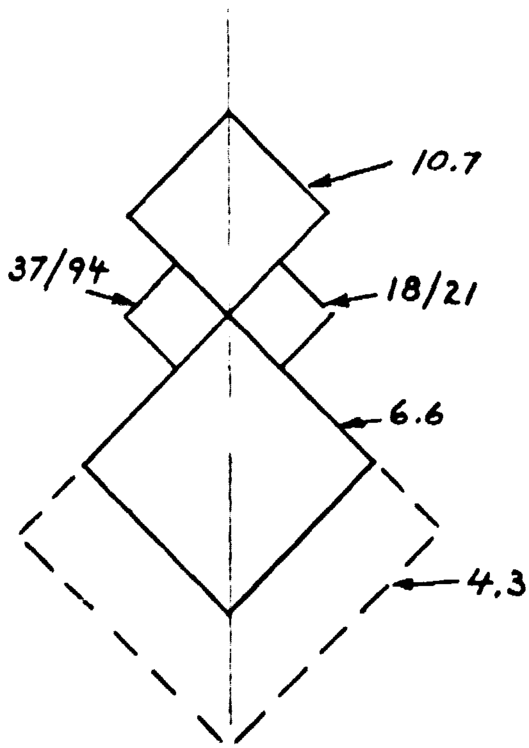
Figure 1 dipicts possible cluster arrangements for conical or pyramidal horns.

Due to the increased spillover from the diffraction side-lobes, and slight beam broadening from off-axis scan, it is estimated that beam efficiencies of 85% can be realized, but not all frequencies would reach 90%. Conversely, several frequencies would require no filtering, hence, I^2R losses would be minimized.

An offset paraboloid fed by a 4 horn cluster operating at five frequencies has been built and tested[5]. Beam efficiencies of 85-90% were achieved.



a) CONICAL HORNS



b) PYRAMIDAL HORNS

FIG. 1 RELATIVE POSITIONS AND SIZES OF
4 HORN FEED CLUSTER APERTURES

2.2.2 Dichroic Subreflector

Cassegrain antennas (dual reflectors) can employ multiple feeds and still produce concentric, high efficiency beams by utilizing a subreflector transparent to a selected frequency or polarization.

If a polarization grid were used as a subreflector, two identical feeds, with six co-linearly polarized signals in each, are required. This does not ease the feed design problems in any substantial way.

Several types of frequency selective reflectors have been developed for use as subreflectors. These have been termed "Quasi-optical Diplexers"[6], "Fenestrated Metal Reflectors"[7,8], "Resonant-Grid Reflectors"[9], "Space Filters"[10,11], and "Dichroic Plates"[12].

The types most useful to the application would be a high-pass (or band-pass) that reflects all lower frequencies. For example, a true high-pass could pass 37 and 94 GHz to a dual frequency horn with different beamwidths and reflect the four lower frequencies to a SMMR type horn.

Since 37 and 94 GHz only use part of the available aperture, each could pass through a different portion of the sub-reflector without interferring. Hence, a narrow band-pass grid that reflects all lower frequencies is adequate. In this case 37 and 94 GHz would have independent feeds.

It is important to note that while some frequencies in this design use different portions of the aperture (and several use the entire aperture), all beams produce concentric footprints in the far field. The concentricty being determined by the alignment of the horns and subreflector.

Good examples of this type antenna is the 19 and 28.5 GHz offset Cassegrain developed by Chu and Legg[13] and the "Quasi-Optical Polarization Independent Diplexer" by Saleh and Semplak[14].

A feasible design approach employs a subreflector which acts as a filter and directs various frequencies to the appropriate feed. An offset hyperboloid subreflector is recommended, which reflects all frequencies below 30 GHz

to a 4 frequency SMMR type feed. (See Figure 2). The subreflector would be approximately 26 inches in diameter. A 16 inch diameter area, offset to one side, would be fenestrated to pass 37 GHz to a feed horn at the prime focus. And a 7 inch diameter area would be fenestrated to pass 94 GHz to a concave hyperboloid and feed horn. This 94 GHz reflector serves the dual purpose of avoiding interference between the 94 and 37 GHz horns and also allows the feed to have a larger, more practical illumination angle.

The most simple type of element for a band pass effect which rejects all lower frequencies, is the square aperture reported by Kieburtz and Isimaru[9]. An analysis for this element, applied to 94 GHz, is summarized in Figure 3, Curve 1. It is found to have adequate bandwidth and good rejection at 21 GHz. The dimensions and tolerances are reasonable. A 7 inch diameter would contain approximately 3500 square apertures which, for example, could be produced by computer generated photo-etching on a .003 inch thick beryllium copper sheet. At 37 GHz a smaller bandwidth and sharper reject skirt is needed, and can be obtained from crossed rectangular apertures. Curve 2 in Figure 3 shows a typical characteristic. Again over 3000 apertures would be needed in the 16 inch diameter. Estimated reflected losses of this reflector are .9 dB at 94

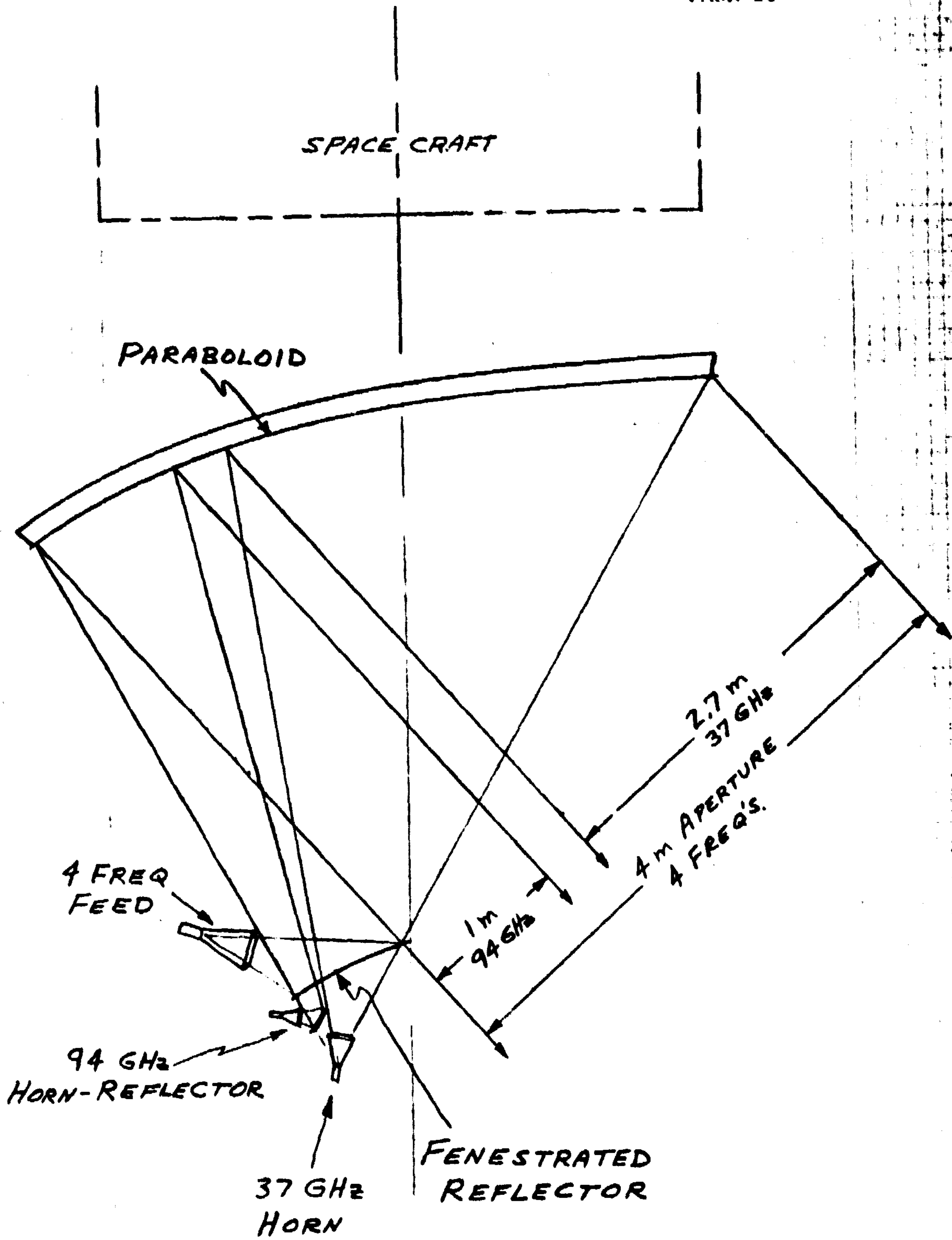
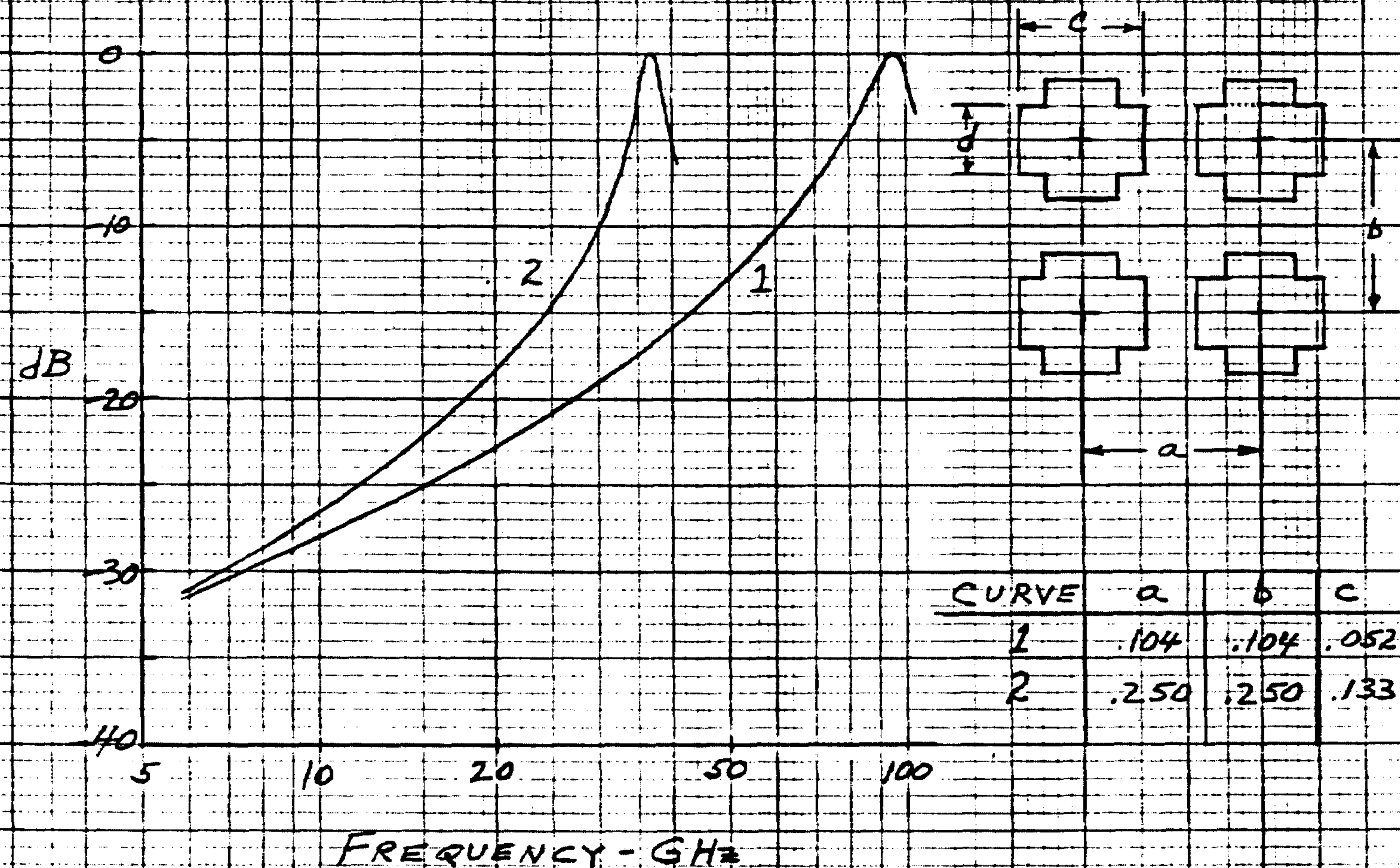


FIG 2. CASSEGRAIN ANTENNA GEOMETRY



CURVE	a	b	c	d
1	.104	.104	.052	.052
2	.250	.250	.133	.037

FIG. 3 TYPICAL FREQUENCY RESPONSE OF FENESTRATED REFLECTOR

GHz and .4 dB at 37 GHz. Dissipative losses are extremely small. Multiple layer, quasi-optical diplexers have been demonstrated and should have lower reflective losses, but would be difficult to fabricate at 94 GHz.

The most difficult aspects of the recommended single layer design are that the photo-etching must be done on a double-curved surface (hyperboloid), and its shape must be maintained within the tolerance required of a subreflector for 21 GHz. (e.g. within approximately ± .010 inches.) Shielding for thermal control may be required.

The cross-polarization of offset paraboloids is of concern and is given by Chu and Turrin[15]. Their results also apply to an offset Cassegrain. As either the illumination angle or the angle between the feed and far-field beam axes increases, cross-polarization increases. The advantage gained in the recommended design is that either the offset angle or the total illumination angle is small for each feed. Hence, all frequencies will have low cross polarization. (e.g. -30 dB peak) Arnaud and Pelow[6] show that the depolarization properties of transmitted and reflected signals from a quasi-optical diplexer are very good for both polarization over a wide range of incident angles. (They also discuss types of apertures, fabrication

techniques and give measured results.)

In this design a feed horn with four frequencies illuminating the full aperture is required (6.6, 10.7, 18 and 21 GHz). This is essentially an SMMR horn with 37 GHz eliminated. It is therefore obvious that such a horn is feasible. In fact, the filters in the 18 and 21 GHz ports can be eliminated and modified in the 10.7 GHz port. Less insertion loss and improved VSWR will be obtained in all 3 channels.

For 37 GHz a prime focus feed radiating through the subreflector and illuminating approximately 2/3 of the full aperture diameter is required. A dual polarized corrugated horn is recommended.

For 94 GHz, a dual polarized feed illuminating about 1/4 of the total aperture diameter, in an area independent of the 37 GHz aperture, is required. Since this feed cannot occupy the same focal point as the 37 GHz unit, and since it has a relatively narrow illumination angle, a horn-reflector, as used in SCAMS[16], is recommended.

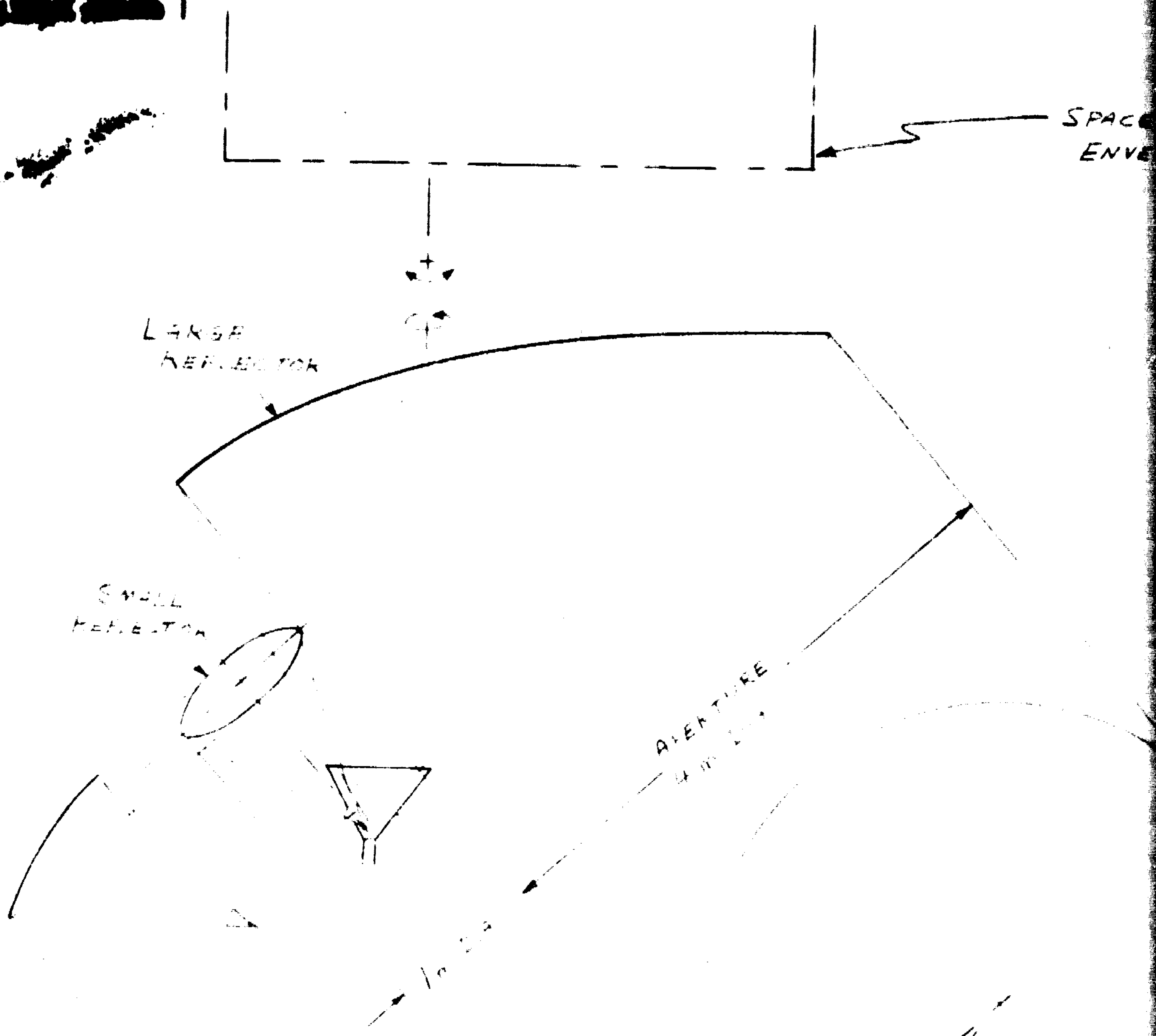
Neither the 37 nor the 94 GHz horns will require any additional filtering. Hence, the losses associated with the quasi-optical subreflector, and with the additional 94 GHz hyperboloid, are not considered excessive.

2.3 Independent Reflector Antennas

When the design difficulties, expenses and reduced efficiencies of the Cassegrain and multiple feed, non-concentric beam approaches are considered and realizing that the higher frequencies only utilize a portion of the main reflector, it becomes a practical alternative to consider a separate reflector antenna for those frequencies. Figure 4 depicts a proposed layout using a four meter diameter offset paraboloid and multifrequency feed operating up to 21 GHz. And a similar, but separate one meter diameter antenna operating at 37 GHz and above. The smaller reflector and feed for the larger reflector are each located off the cardinal plane such that they occupy minimum space and will not block each other. With proper orientation of each feed, all polarizations can be aligned in the cardinal planes. The feeds are located near each other to simplify the electronics packaging.

This two antenna approach is considered only slightly larger and heavier than the offset Cassegrain. In fact, the arrangement of the smaller reflector can be optimized to aid in the dynamic balancing of the larger reflector.

The feed for the larger antenna would operate at four frequencies, and is the same as the feed illuminating the subreflector of the



FOLDOUT FRAME 1

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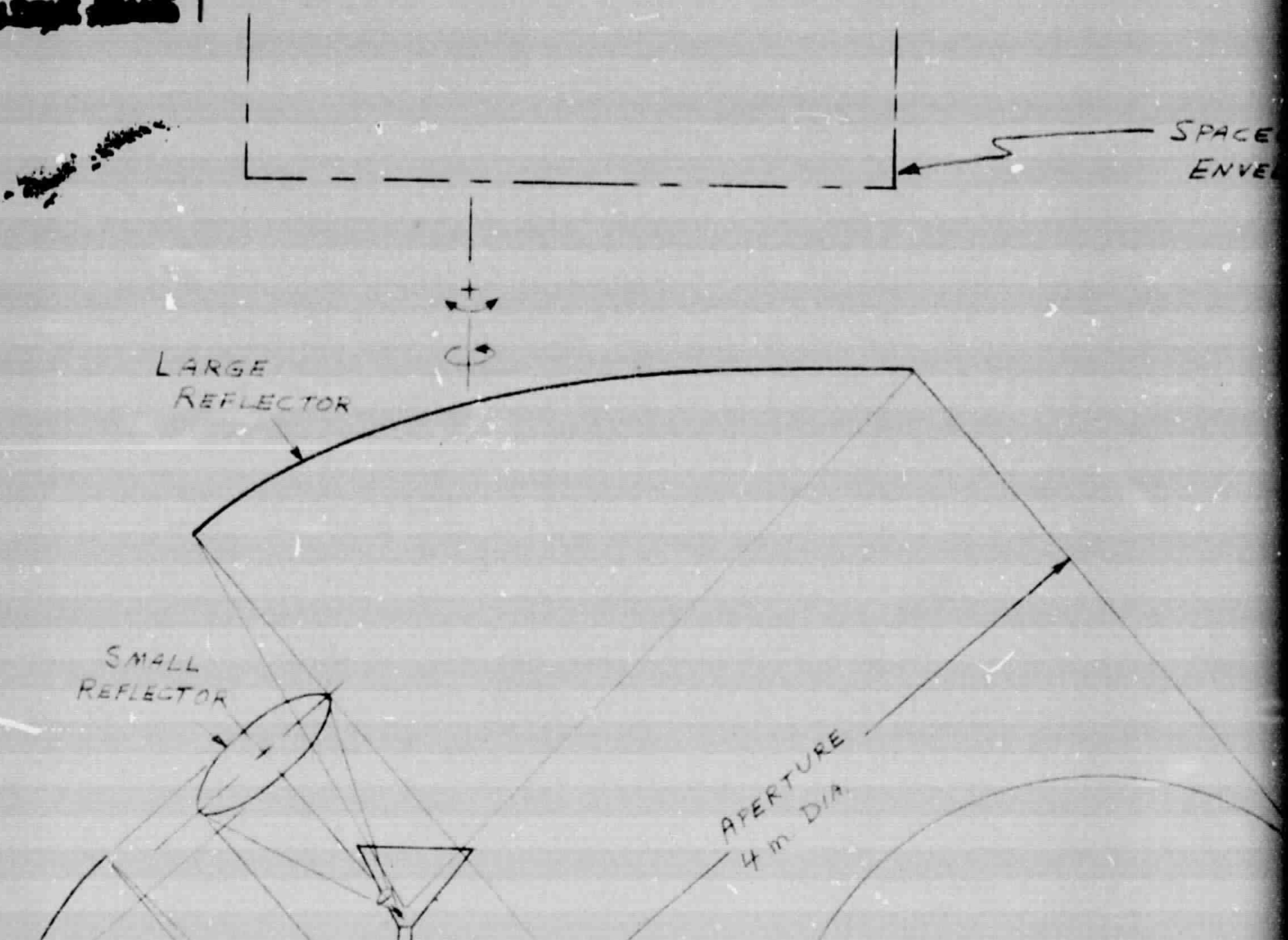

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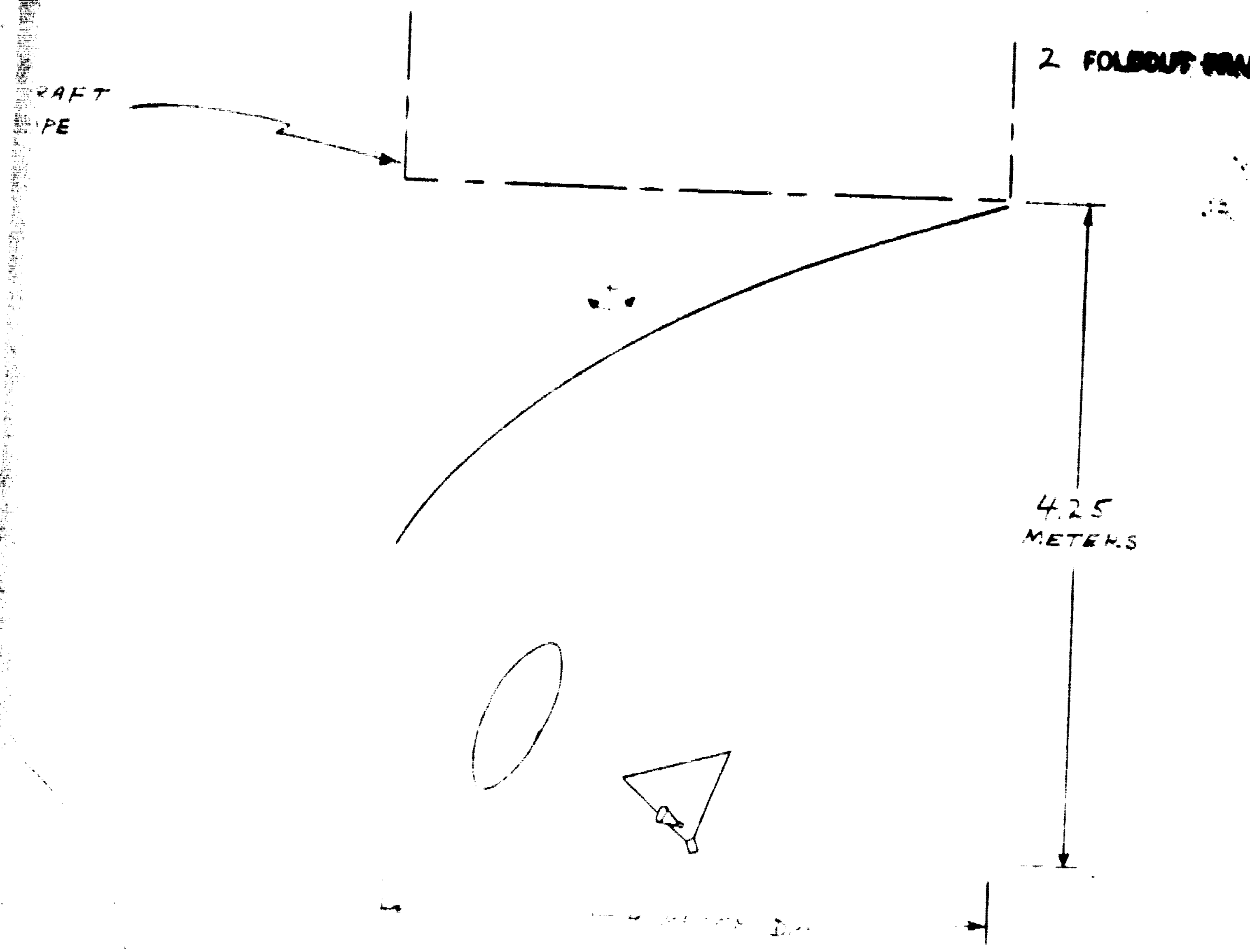

FIGURE 4
1R. [illegible] LAYOUT
2 ANTENNA CONCEPT

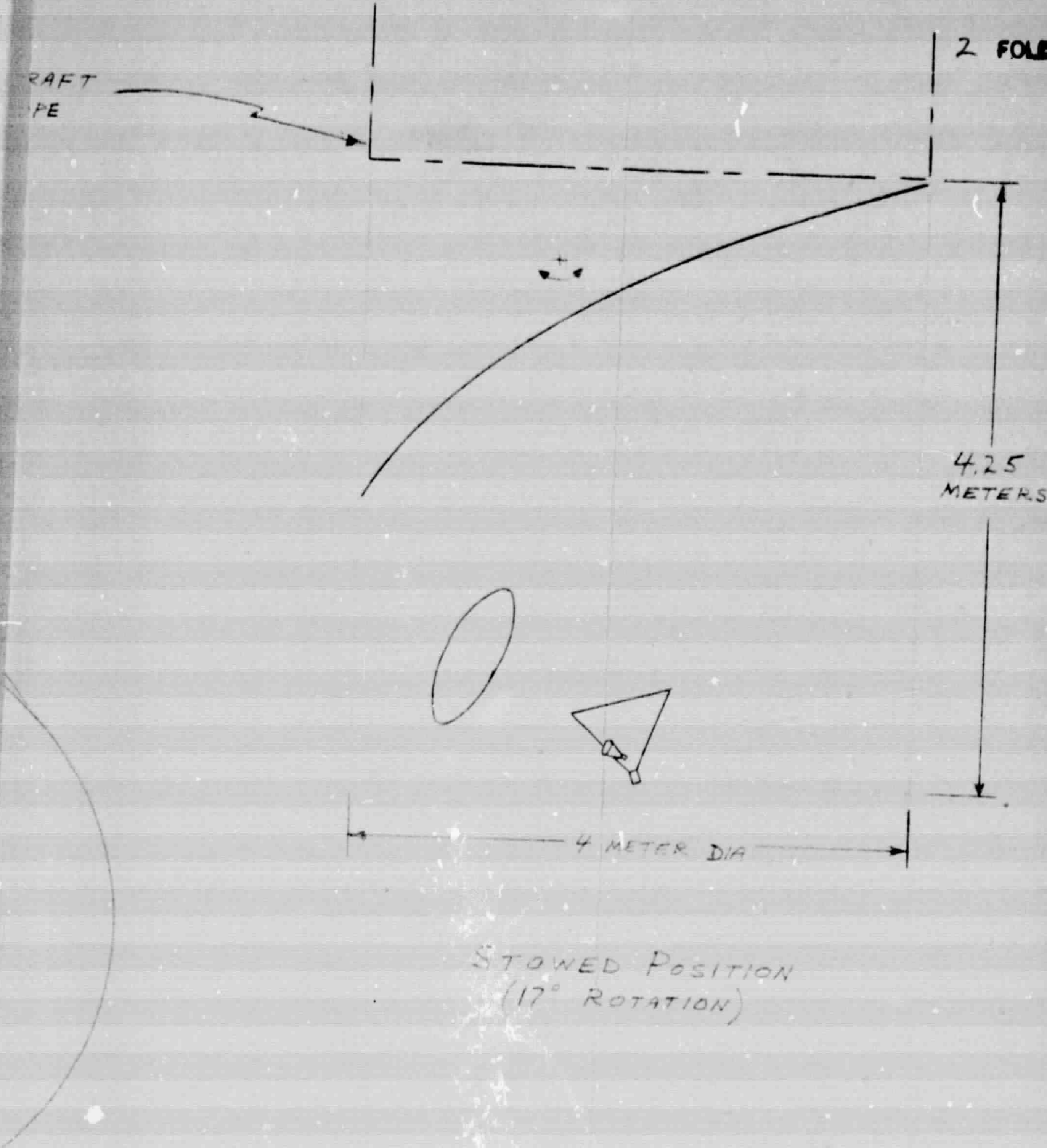

FIGURE 4
PROPOSED LAYOUT
2 ANTENNA CONCEPT

Cassegrain design. All four frequencies utilize the full four meter diameter aperture.

The feed for the smaller reflector would be a relatively simple corrugated conical horn operating at two or more frequencies. The full aperture is utilized at each frequency. Resulting beamwidths would be 0.6° at 37 GHz and 0.25° at 94 GHz.

3.0 OTHER CONSIDERATIONS

3.1 Substitution of 4.3 GHz

If desired, 4.3 GHz can be substituted in place of 6.6 GHz in all three of the design approaches discussed herein. In the 4 horn cluster feed, the large horn can be replaced with a 4.3 GHz horn. Since the horn will be larger, it will be further off-axis so the the beam produced will be displaced by a larger angle. However, the beamwidth will be larger also. (1.3° rather than 0.85°) In this case, it is possible to design this large horn to accomodate both 4.3 and 6.6 GHz simultaneously. However, the 4 meter reflector would be under illuminated at 6.6 GHz and would produce a beam concentric with the 4.3 GHz beam and with a wider beamwidth of about 1.1°.

In the cases of the two design approaches incorporating a 4 frequency, wide-flare corrugated conical horn the 6.6 GHz input through the sides of the horn can be scaled up in size to operate at 4.3 GHz. The corrugations in the horn must also be changed, and the horn must be made larger. (About 11 inches rather than 7.5 inches in diameter.) It does not appear feasible to design the corrugations to accomodate 4.3 and 6.6 GHz simultaneously with 10.7, 18, and 21 GHz also present. i.e. a 4 frequency horn with a low frequency of 6.6 or 4.3 GHz can be achieved, but a horn combining those five frequencies is very difficult.

For a Cassegrain operating at 4.3 GHz, the minimum subreflector size is about 1 meter diameter.

3.2 Addition of 1.4 GHz

Consideration was given to adding a 1.4 GHz channel to each design approach. This cannot be done to the Cassegrain antenna feed as the subreflector is too small to perform efficiently at the longer wavelength. A prime focus feed offset to the side of the subreflector is the only method of adding 1.4 GHz. This would yield a 4° beam, about four beamwidths off-axis. It is estimated that the beam efficiency would be less than 90%.

1.4 GHz can be added to the prime focus, 4 frequency horn by extending its size up to one meter in diameter. The addition of 1.4 GHz appears compatible with either 4.3 or 6.6 GHz in addition to 10.7, 18 and 21 GHz. In this way, a beam efficiency of 90% can be achieved at the expense of a large prime focus horn.

It appears feasible to add 1.4 GHz to the 4 horn cluster feed by packaging a flat-plate array of crossed slots around the horns. In the case using 6.6 GHz, without 4.3, the horns are small enough to fit in the spaces between slots, yielding a 4° beam at 1.4 GHz which overlaps the cluster of smaller beams. When using 4.3 GHz, its horn would be too large to fit between slots, and the array would be displaced to one side, about 1/2 beamwidth. The flat plate array would

be less than 20 inches diameter an contain 8 to 16 sets of crossed slots. Feeding to the cavity backed slots would be by a coaxial/stripline power divider.

3.3 Addition of 55 GHz

Recognizing the interest in using three closely spaced, linearly polarized channels near 55 GHz, consideration was given to such an addition.

In the case of the cluster feed, three ports could be added to the 37/94 GHz horn. For example, 52.8 and 55.4 GHz could be co-polarized, and 53.8 GHz orthogonally polarized. These frequencies, in a 1.6 inch horn would illuminate about 1.3 meters of the reflector and generate beams of about 0.3°.

Similarly, these frequencies can be added to the separate feed for the one meter reflector in the two reflector systems. In this case, the resulting beams would be 0.4°.

Addition of such frequencies to the Cassegrain design can be done only by adding a third feed radiating through the subreflector in an area unused by 37 or 94 GHz. Illumination of an aperture of up to one meter diameter can be realized using a horn-reflector similar to the SCAMS[16] design. However, insertion loss in the dichroic subreflector would be about 0.6 dB and all frequencies added would have to be within a 3% band due to the bandwidth limitation of the dichroic reflector.

4.0 SUMMARY

The initial consideration of adding 94 GHz to an SMMR horn and changing the illumination angles of 37 and 94 GHz has been found to be not feasible.

Three other design approaches have been considered and evaluated.

1.) An offset Cassegrain with a dichroic subreflector.

2.) A prime focus feed cluster producing offset beams.

3.) A large and small reflector combination, each operating at several frequencies.

The offset Cassegrain was found capable of meeting the outlined goals of a six frequency system, with the disadvantages of having a complex, expensive subreflector with Earth directed spillover.

The prime focus feed cluster is a simple design, but not capable of achieving 90% beam efficiency unless the focal length is extremely long. The beam footprints produced will not be concentric. Due to the spatial isolation between beams, RF filtering and losses are minimized.

The two antenna concept is judged the most practical and versatile approach. The added one meter reflector is no larger than the subreflector of the Cassegrain. And the added focal length necessary for a cluster design would add similar size and weight also. The large reflector need not have the close tolerances necessary for 37 and 94 GHz. RF filtering is less than in a single aperture design. All beam footprints are concentric. However, beamwidths obtained will be determined by the chosen sizes of the two reflectors.

A 1.4 GHz channel can easily be added to the two antenna design and to the prime focus cluster design. The only feasible method of adding it to the Cassegrain design results in an off axis beam with reduced beam efficiency.

Channels around 55 GHz can also be added to the two antenna and feed cluster designs with only minimal addition of filtering losses. Addition of 55 GHz channels to the Cassegrain design adds further substantial complexity to the dichroic subreflector and will be limited in bandwidth attainable.

REFERENCES

1. Love, A.W., Ed. Electromagnetic, IEEE Press, 1976, Part V 'Multi-mode Horns"

2. Takeda , F. and Hashimoto, T., "Broadbanding of Corrugated Conical Horns By Means Of The Ring-Loaded Corrugated Waveguide Structure", IEEE Trans A&P, pp 786-792, NOV 76

3. Turrin, I.H., "Dual Model Small-Aperture Antennas", IEEE A&P, MAR 67, p 307,8

4. Potter, P. "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths", Microwave Journal, JUN 63, p 71

5. McDonald, D. et. al. "Development of the Multispectral Active/Passive Microwave Imaging System", Final Report by Aerojet Electrosystems under NASA/Langley Contract NAS1-13230, MAR 1976

6. Arnaud and Pelow, "Resonant Grid Quasi-Optical Diplexers", BSTJ, FEB 1975, pp 263-283

7. Oh, Lunden and Chiou, "Fenestrated Metal Radome", The Microwave Journal, APR 1954, pp 62-66

8. Oh and Lunden, "A Slotted Metal Radome", The Microwave Journal, MAR 1968, pp 105-108

9. Kieburtz and Isimaru, "Scattering by a Periodically Apertured Conducting Screen", IEEE Trans on Ant. and Prop., NOV 1969, pp 506-514

10. Woodward, "Space Filter", U.S. Patent 4,017,865

11. Murk, "Space Filter", U.S. Patent 4,125,841

12. Potter, P. "Dichroic Plate", U.S. Patent 3,924,239

13. Chu and Legg, "A 19 and 28.5 GHz Quasi-Optical Feed for Offset Cassegrain Antenna", IEEE AP-S Symposium Digest, OCT 1976, pp 6-9

14. Saleh and Semplak, "Quasi-Optical Polarization Independent Diplexer", IEEE Trans. Ant. and Prop., NOV 1976, pp 780-785

15. Chu and Turrin, "Depolarization Properties of Offset Reflector Antenna", IEEE Trans. on Ant. and Prop., MAY 1973, pp 339-345

16. Green, K., "High Efficiency Horn Reflector Antenna", U.S. Patent 3,949,404